Flow Interactions and Control

08 MAR 2012

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Integrity ★ Service ★ Excellence

Report Documentation Page

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NAME: Douglas Smith

BRIEF DESCRIPTION OF PORTFOLIO:

Foundational research examining aerodynamic interactions of laminar/transitional/turbulent flows with structures, rigid or flexible, stationary or moving.

Fundamental understanding is used to develop integrated control approaches to intelligently modify the flow interaction to some advantage.

LIST SUB-AREAS IN PORTFOLIO:

Flow Physics for Control

Flow Control Effectors

Low Reynolds Number Unsteady Aerodynamics

Aeromechanics for MAVs

Inspiration …

Parameter boundaries

BOUNDARIES

LOW

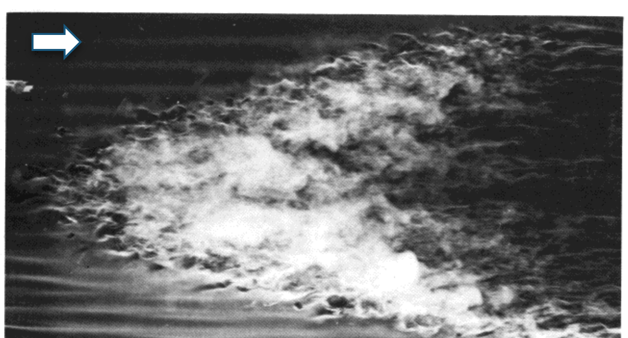
HIGH

R e y n o l d s #

Transition

Laminar Flow

- Smooth & orderly

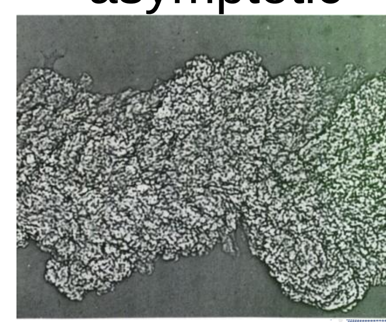


Affected by …

- Roughness
- Freestream turbulence

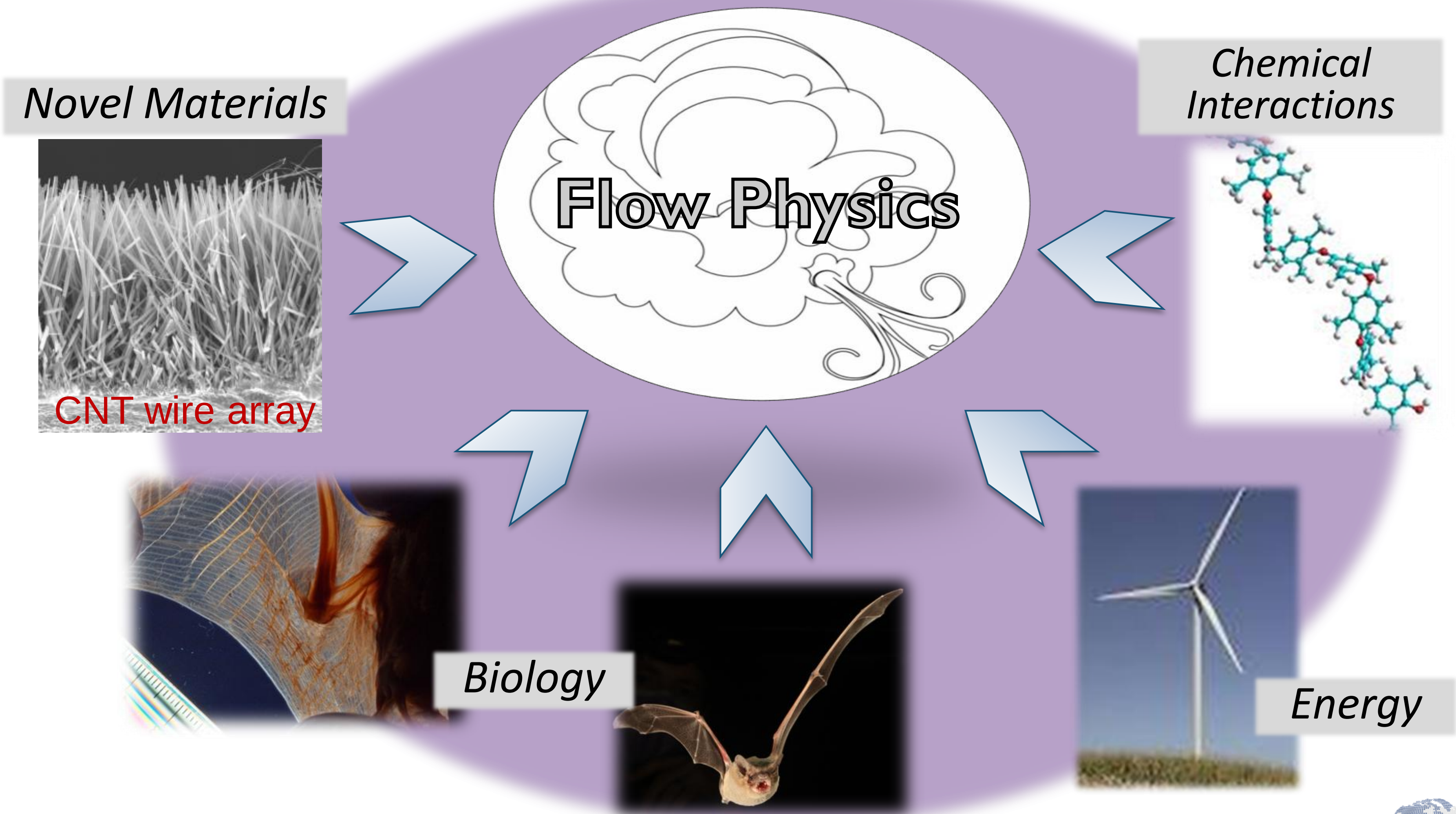
Turbulent Flow

- Disorderly, but asymptotic



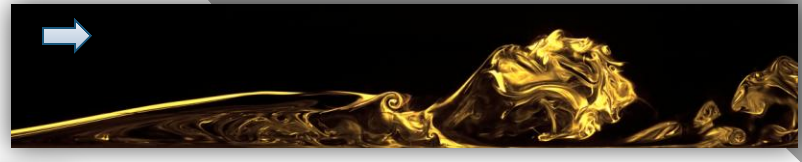
Inspiration …

Disciplinary boundaries

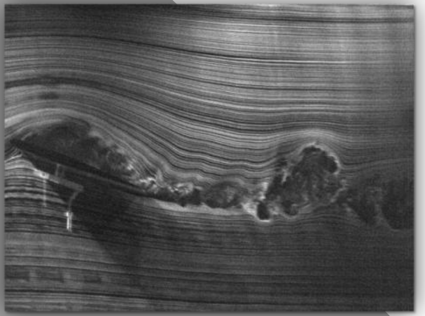


Scientific Challenges

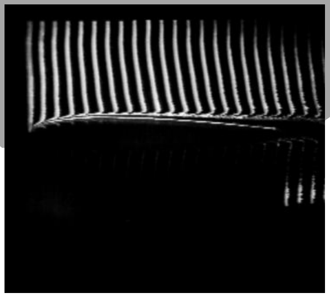
Unsteady Low Rey Aero

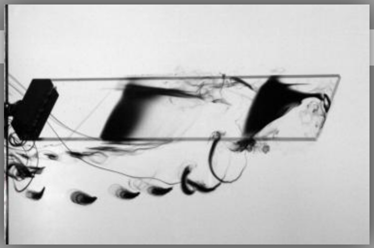


Flow Physics for Control

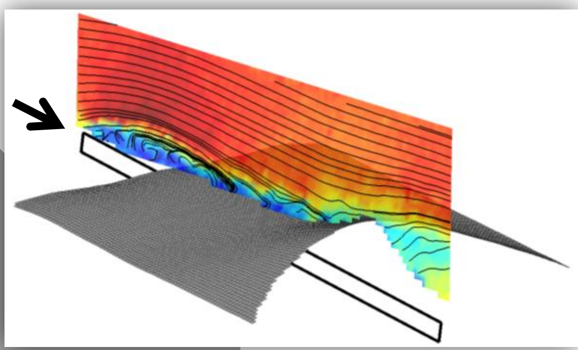


Flow Control

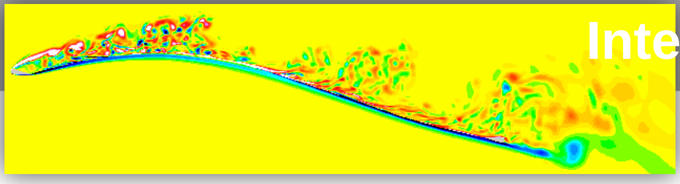




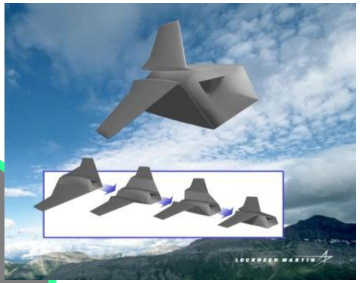
Fluid-Structure Interaction



Flow Control



Opportunities …



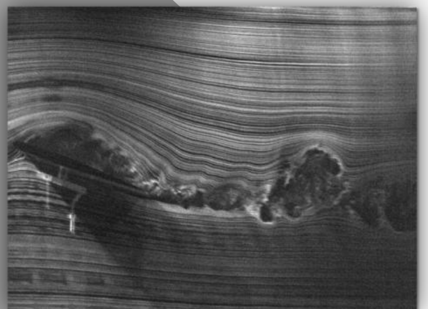
- Create opportunities in
  - ✓Gust tolerance/mitigation
  - ✓Agility
  - ✓Hover
  - ✓Integrated lift & thrust
- Reconfigurable aircraft
- Coordinated flight, swarming
- Drag reduction, Enhanced efficiency

Require an understanding of aerodynamic-structure interactions and control.

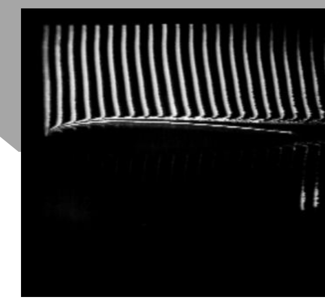
Scientific Challenges

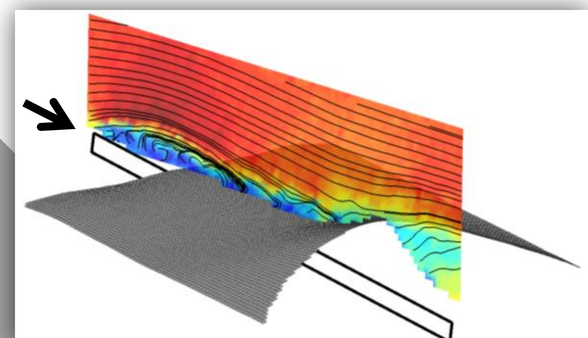
Flow Physics for Control

Unsteady Low Rey Aero



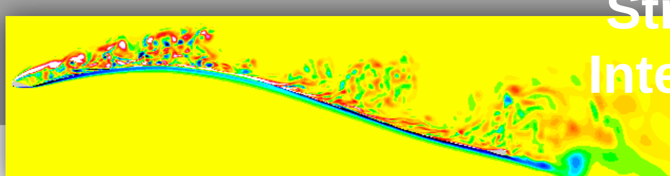
Flow Control



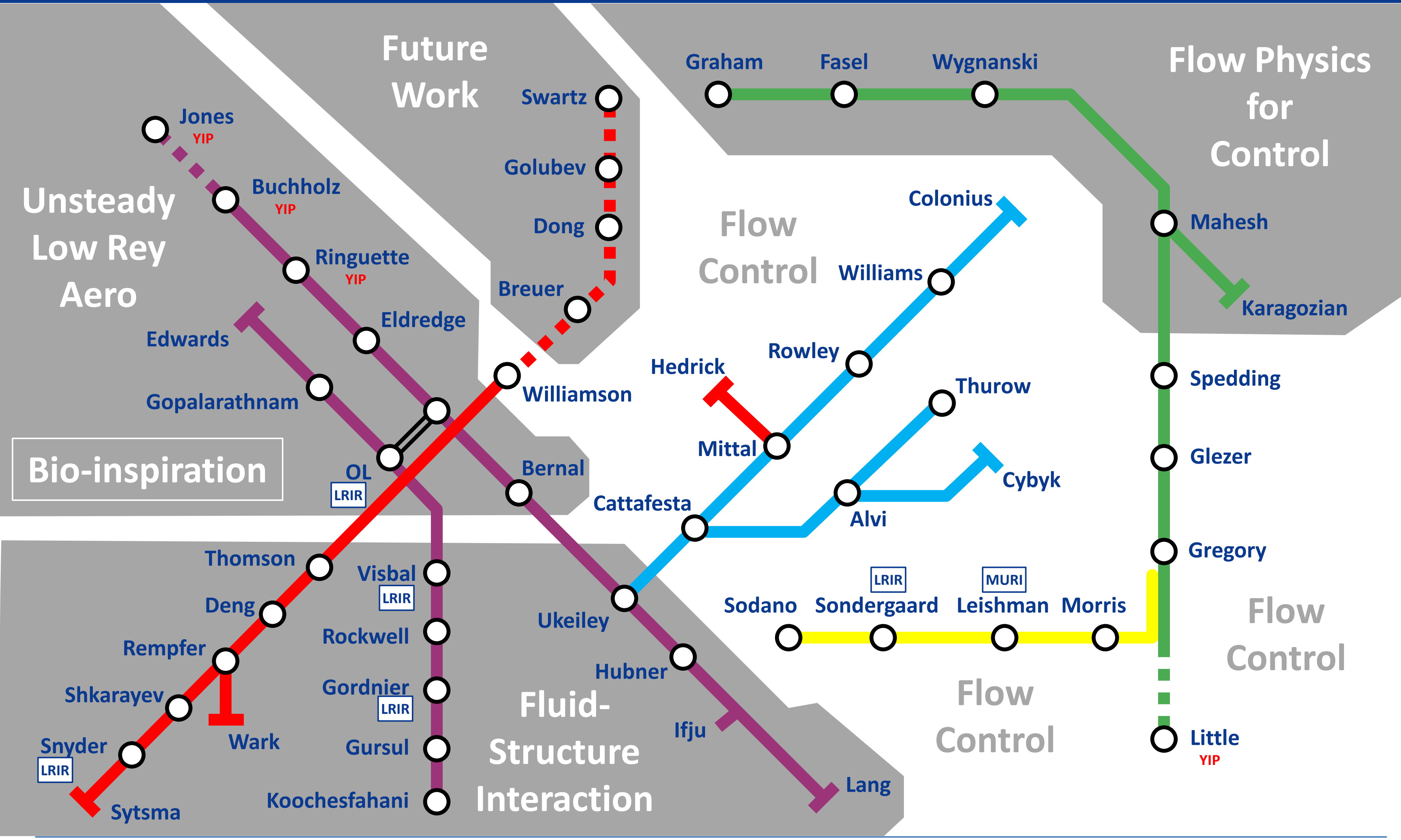


Flow Control

Fluid-Structure Interaction



Portfolio map

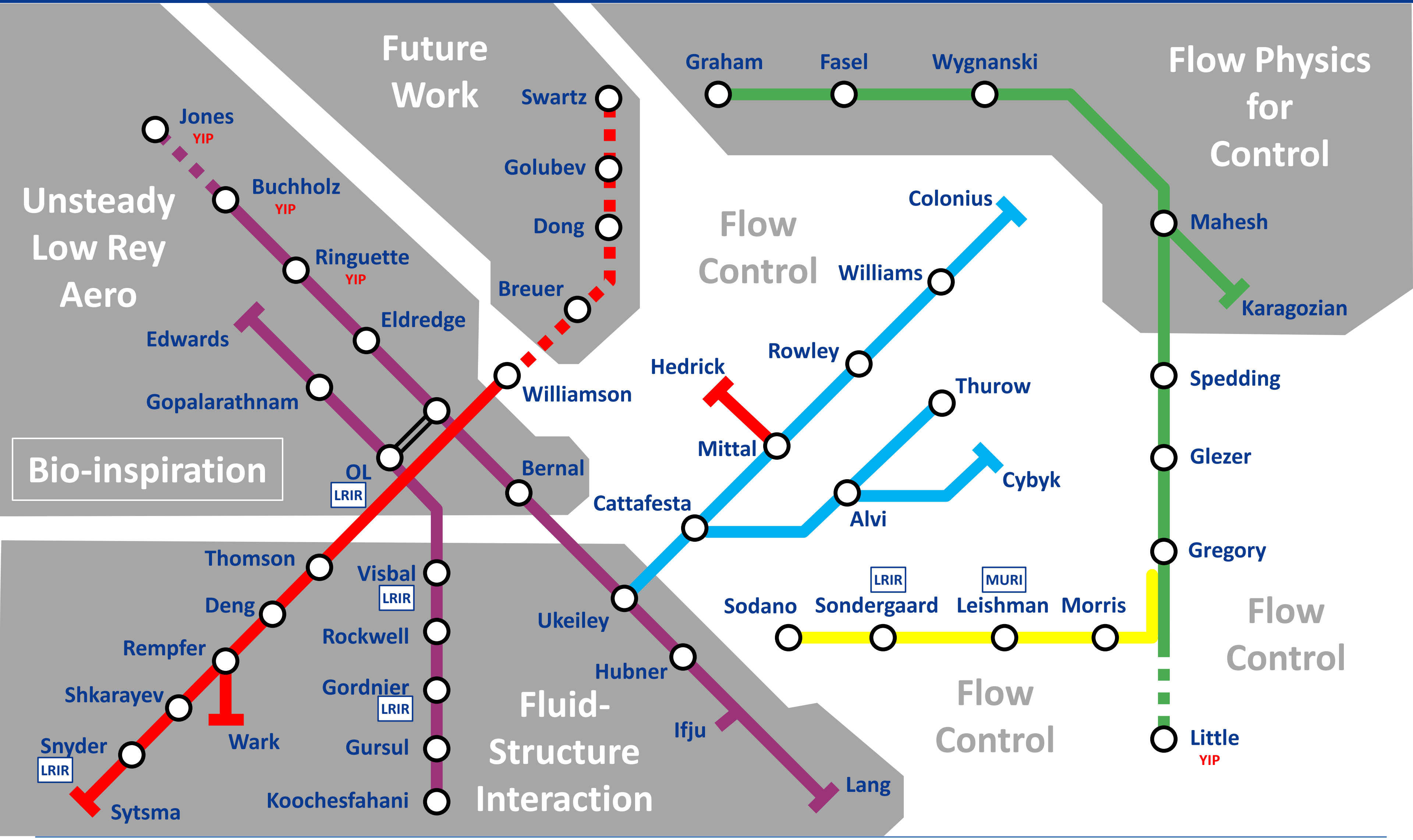


Key to Lines

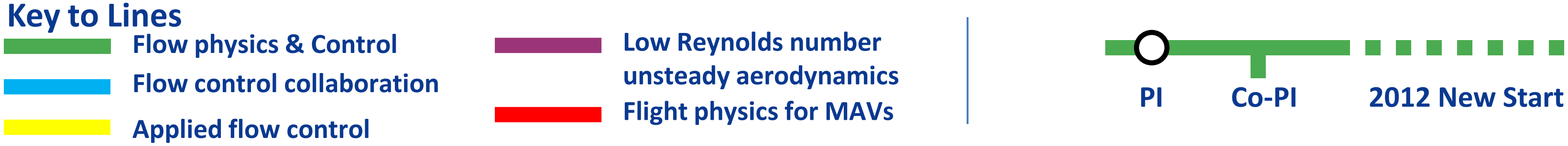
- Flow physics & Control
- Flow control collaboration
- Applied flow control
- Low Reynolds number unsteady aerodynamics
- Flight physics for MAVs

PI Co-PI 2012 New Start

Portfolio map



Key to Lines



Exploiting the nonlinear dynamics of near-wall turbulence for skin-friction reduction

M. Graham, Wisconsin

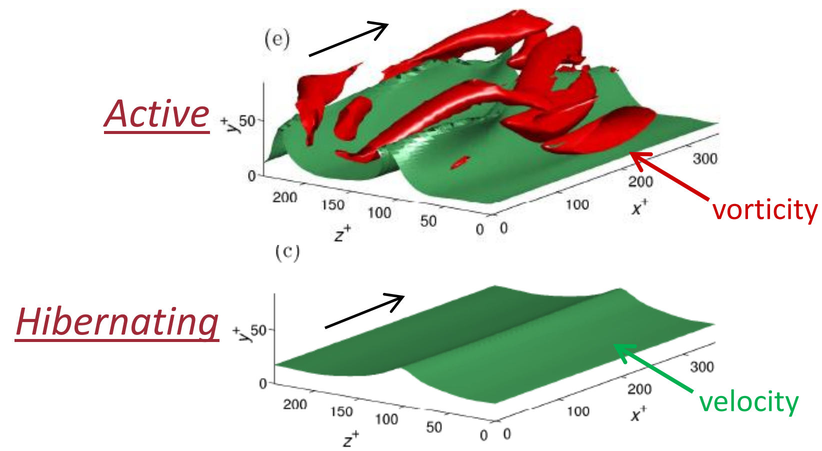
Background and objective

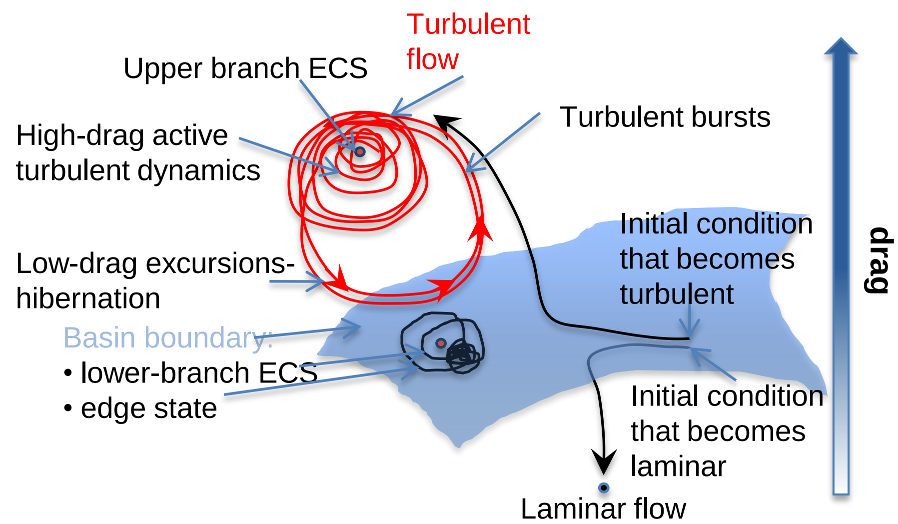
- Drag in many aerodynamic flows is dominated by near-wall turbulent flow structures
- Approaches to skin-friction reduction often focus on manipulation of these structures via suction/blowing or topography (riblets)
- In liquids, dramatic changes in these structures and corresponding high levels of drag reduction (>70%) can be achieved by adding long-chain polymers.

- Recent discoveries:
  - polymer stresses suppress normal "active" turbulence" but do not affect intervals of "hibernating" turbulence that exhibit very low skin friction,
  - hibernating turbulence intervals are found occasionally ***even without polymer additives.***

⇒Goal: Exploit these observations to develop new boundary control schemes to make these low-drag intervals more frequent and thus reduce overall drag in aerodynamically important flows.

Recent results

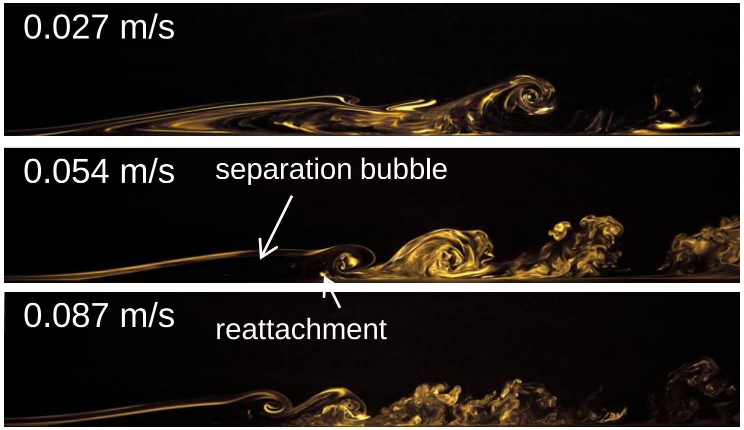


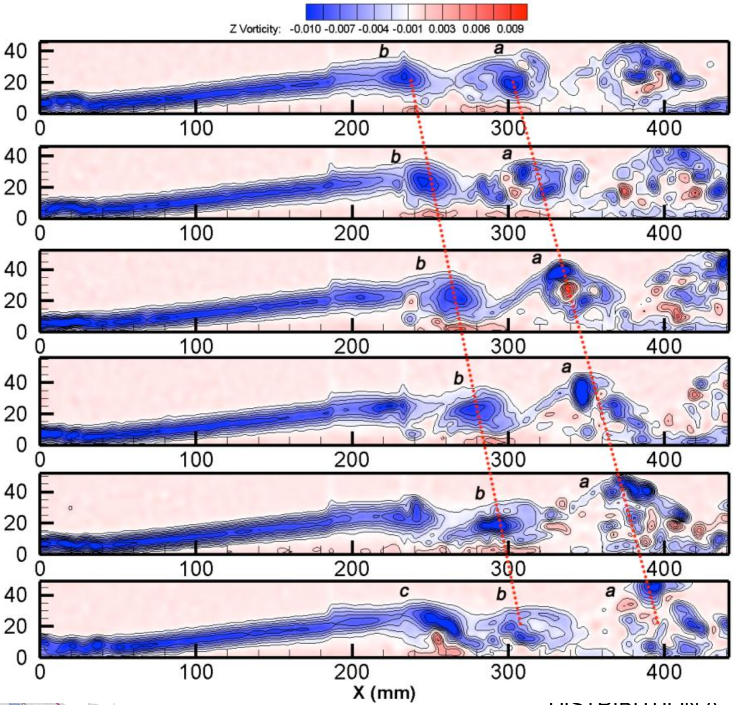


Proposed schematic of the state space dynamics of turbulent wall-bounded flow.

Control of boundary-layer separation for lifting surfaces

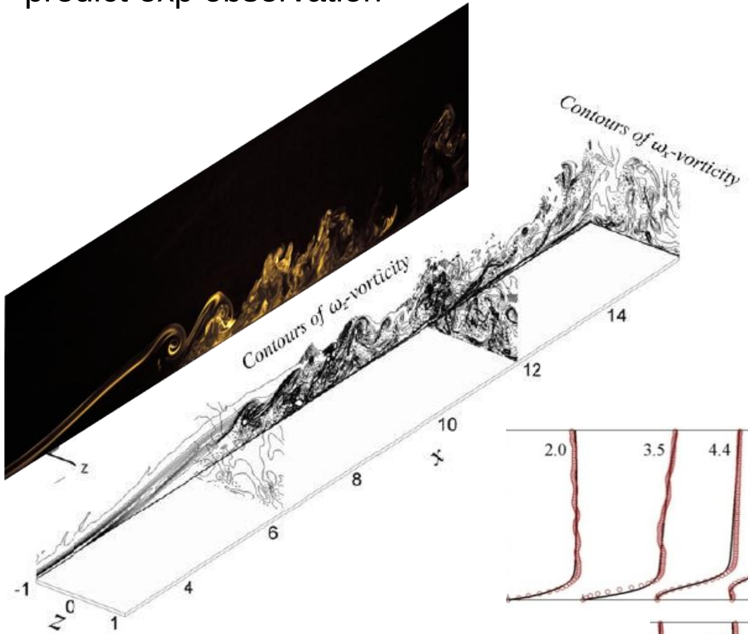
H. Fasel, Arizona

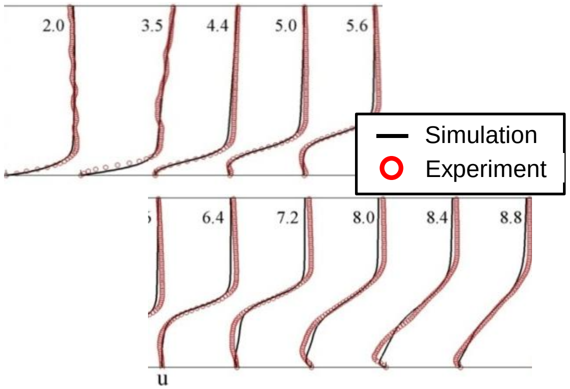




Investigating the transition process of separation bubbles in the presence of freestream turbulence

- Experimental observations → description of bubble behavior
- Simulations require that freestream turbulence is included to predict exp observation

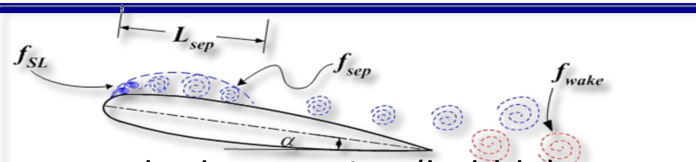




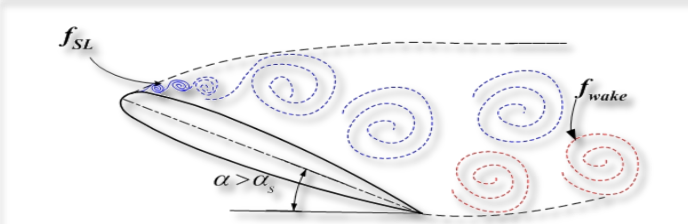
Profiles of time-averaged u-velocity

AN INTEGRATED STUDY OF SEPARATION CONTROL

L. Cattafesta (FSU), R. Mittal (JHU), & C. Rowley (Princeton)



Reattached separation (bubble)

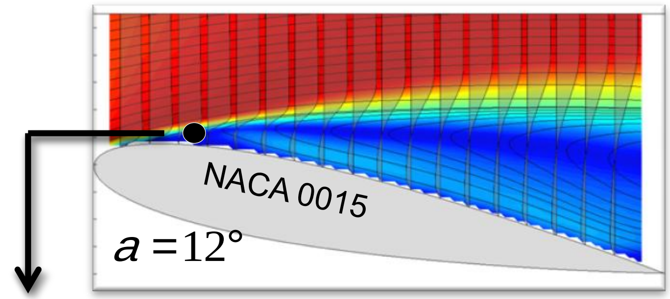


Detached separation

1) Investigate nonlinear interactions between these phenomena
2) Leverage nonlinear interactions for effective control strategies

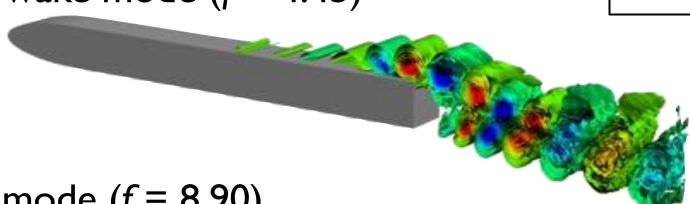
EXPERIMENTS

- **Investigation into nonlinear coupling of stalled airfoil**

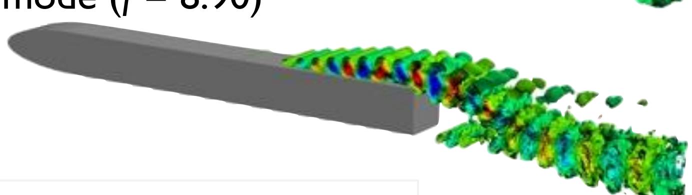


- **Shear layer probe reveals quadratic coupling → nonlinear coupling between shear layer and wake instabilities**

SB/wake mode (f = 4.45)

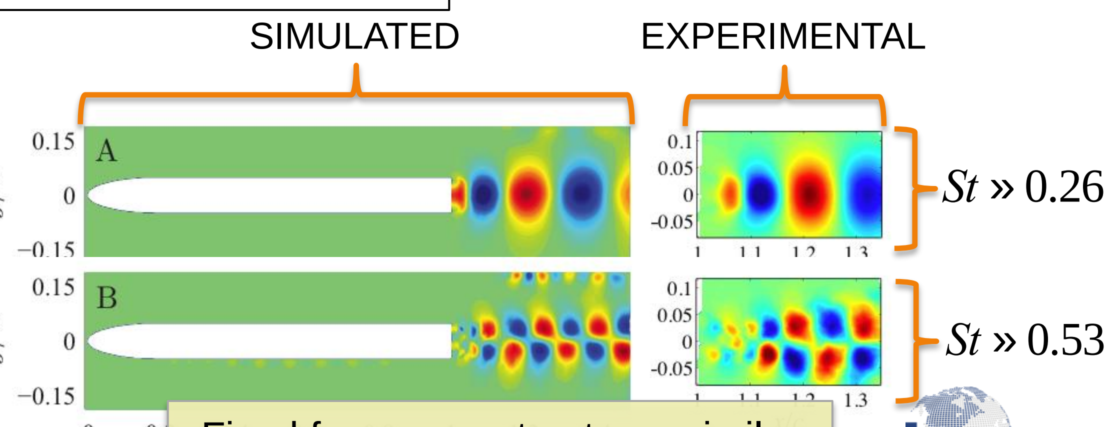


SL mode (f = 8.90)



Oscillating structures

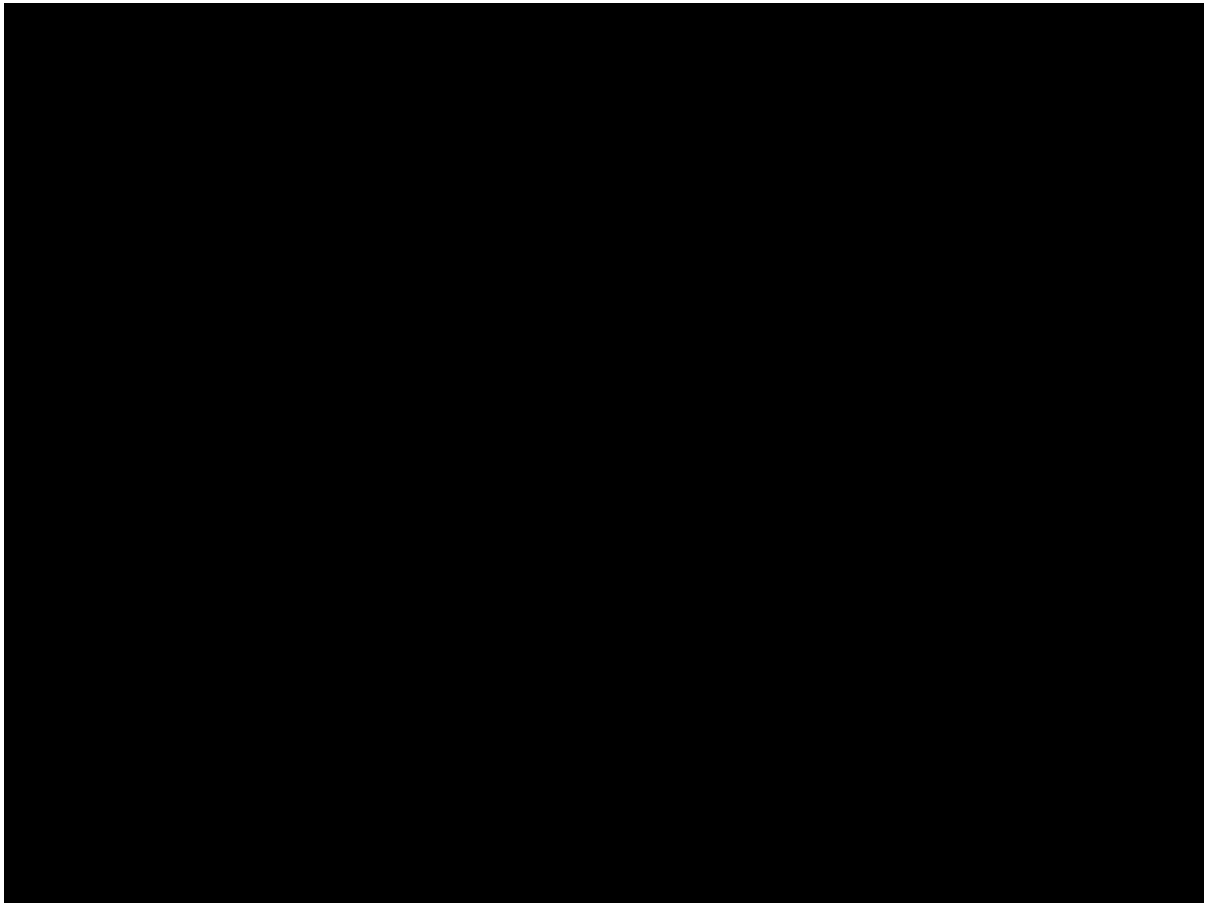
DYNAMICAL ANALYSIS



Fixed frequency structures similar

Rotorcraft Brownout – Advanced Understanding Control and Mitigation

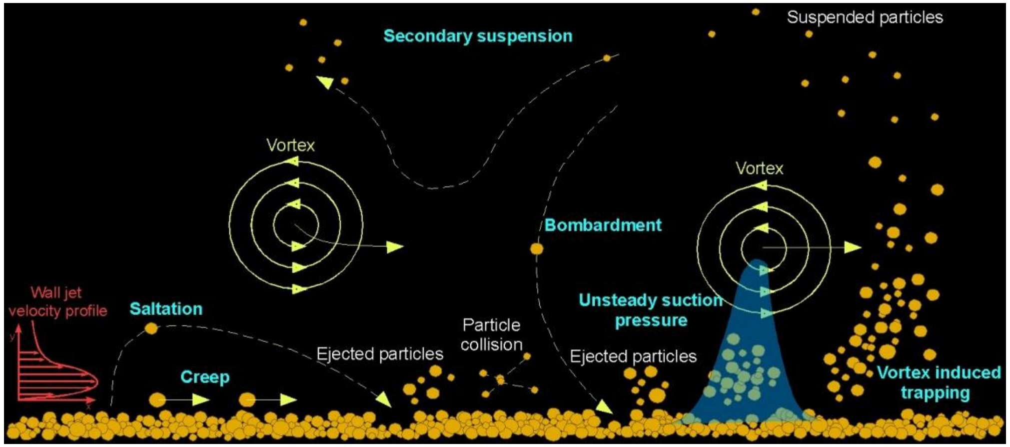
G. Leishman, Maryland



Rotorcraft Brownout – Advanced Understanding Control and Mitigation

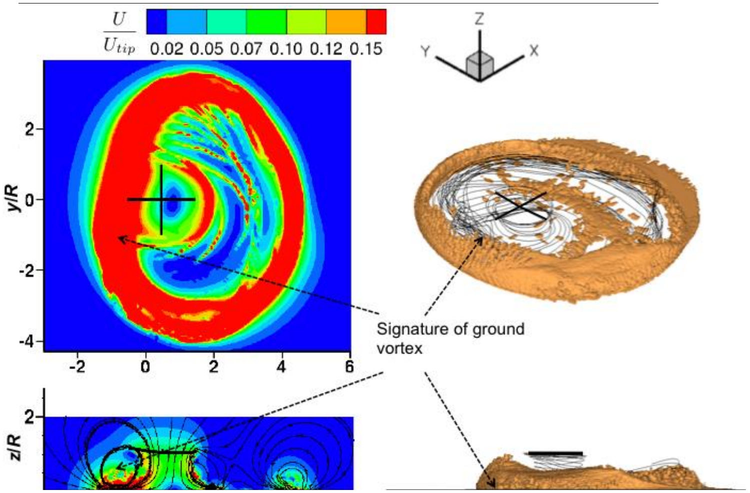
G. Leishman, Maryland

- Rotor wake dynamics "in ground effect" is at the root of the problem
- Unsteady, 2-phase, 3-dimensional fluid dynamics problem
- Wake impinging on the ground creates:
  - Transient excursions in flow velocities
  - Unsteady shear stresses and pressures
  - Secondary vortical flows and local regions of flow separation
  - Turbulence



Summary of the six sediment mobilization, uplift, and suspension mechanisms observed from a bed below a rotor: creep; modified saltation, vortex-induced trapping, unsteady suction pressure effects, secondary suspension, particle bombardment/splash

; dist

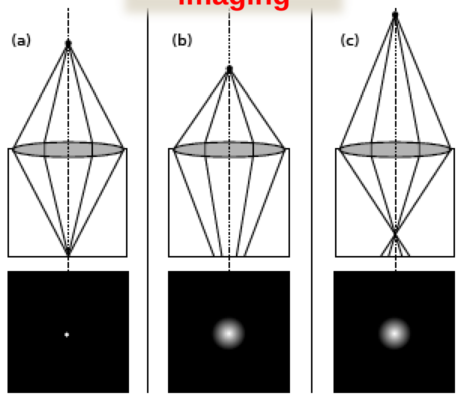


Simulated dust clouds using a Lagrangian free-vortex rotor wake method and Lagrangian sediment particle tracking method (~10^{12} particles) along with contours of induced velocity on the ground (note high 3-dimensionality) for a dynamic simulation of a helicopter landing over a surface covered with a sediment bed

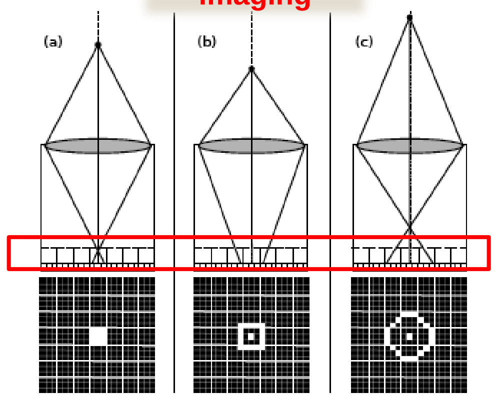
Development of a Compact and Easy-to-Use 3-D Camera For Measurements in Turbulent Flow Fields

B Thurow, Auburn

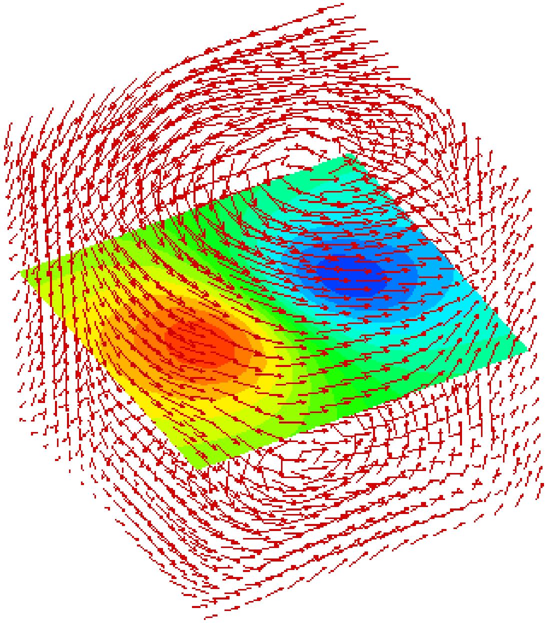
Conventional imaging



Plenoptic imaging



Lense-l



Conventional 2-D Imaging Systems

- 2-D information neglects inherent 3-D nature of turbulent flows
- Camera integrates angular information, which leads to depth-of-field and blur
- Reduced aperture (restricted angular information) leads to low signal levels

Lightfield Imaging

- Plenoptic camera records both the <u>**position and angle**</u> of light rays that enter the camera
- Eliminates the need for complex, expensive multi-camera arrangements
- Dense sampling of 3-D scene

Biological Inspiration

Courtesy of Breuer & Swartz, Brown

Challenges & Questions

CHALLENGES	QUESTIONS
Unsteady, periodic flow-fields	To what extent can the flow be treated as quasi-steady?
Three-dimensional flow-fields	Can the flow be treated as 2-D along the span of the wing? What can we learn from these 2-D treatments?
Low Reynolds number flows	How good are inviscid approximations?
Laminar-transitional flows	How well must these flows be resolved?
Separation & Leading-edge vortices	Why separated flow? Do LEVs have universal formation scaling?
Wing kinematics	How sensitive are the aerodynamics to the kinematics? Rectilinear vs flapping?
Wing flexibility	What is the role of flexibility in modifying aerodynamic efficiency?

Bio-Inspired Aerodynamics

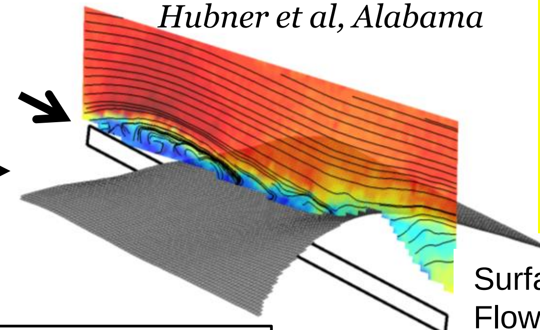
HIGH

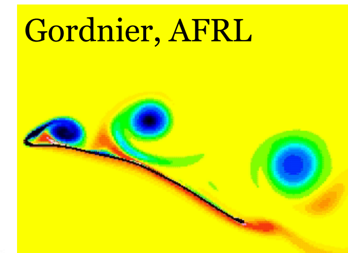
Bio-Inspired Flight

3D aero-elastic, dynamic flight
Neuro-physiological control
Evolutionary biology

Aerodynamics & Flexibility

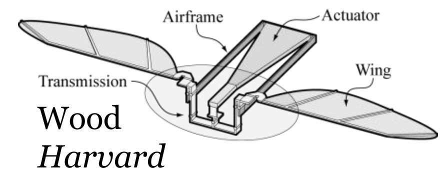
Wing Structure



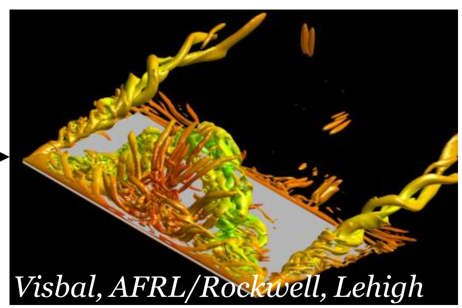


Surface flexibility/compliance
Flow induced vibrations
Natural, passive flow control

Source: Wikimedia Commons



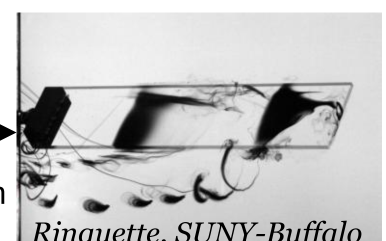
Hi-fidelity Simulations



3D/wing tip effects
Transition to turbulence

Rigid Wing Aerodynamics

Starting/stopping transients
Leading edge vortex formation
Universal scaling



OL, AFRL

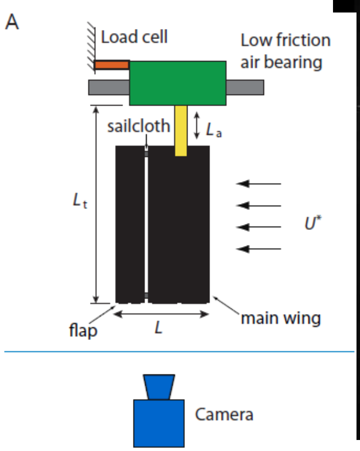
LOW

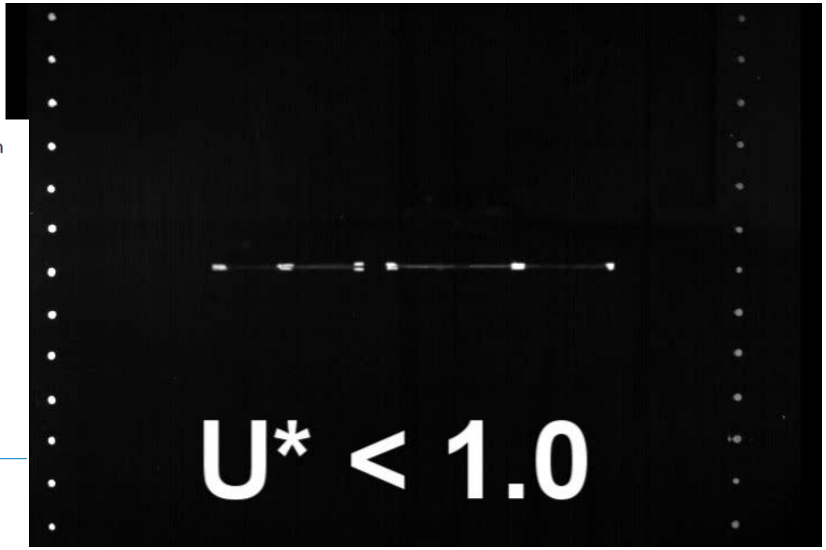
From Gliding to Powered Flight

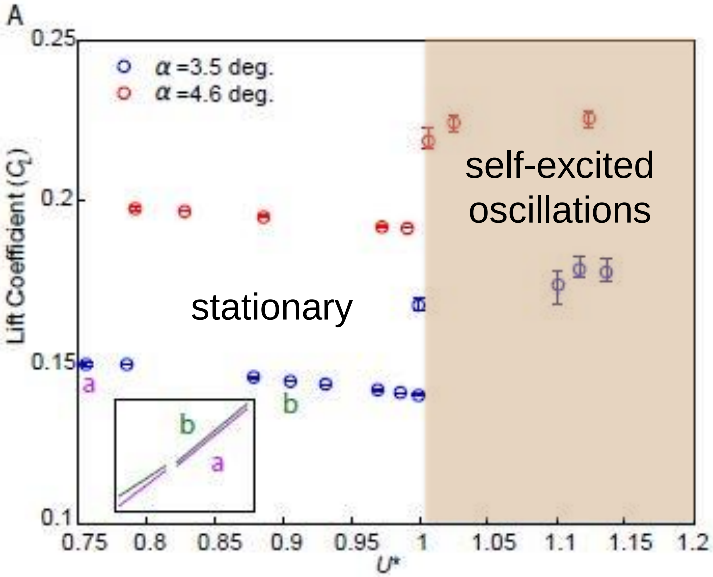
Onychonycteris finneyi

50 million years ago bats evolved from gliding to powered flapping flight. BUT…

- What pressures led from passive gliding to powered flight?
- What is the role passive wing deformation or motion in biological flight?

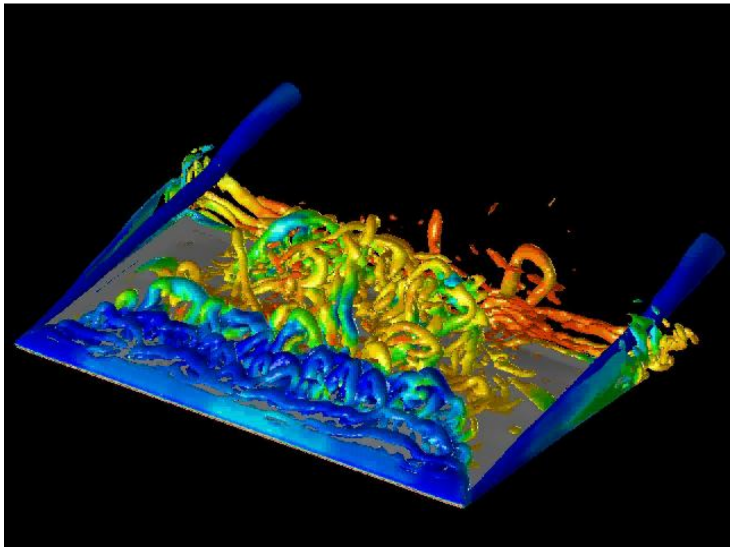






Effect of Membrane Flexibility on Leading Edge Separation

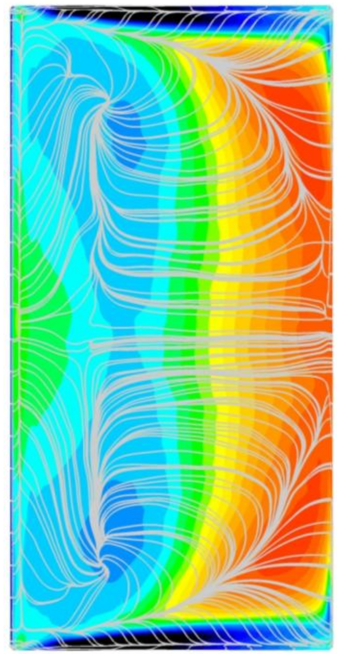
R Gordnier, AFRL/RBAC



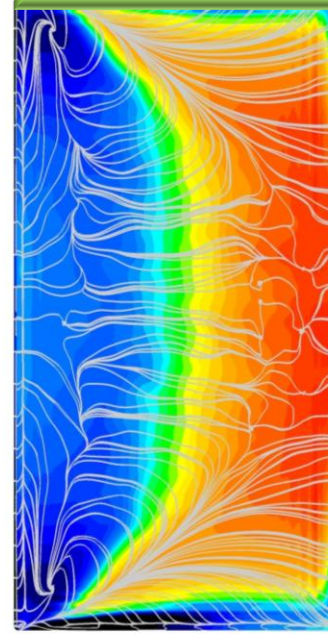
Membrane Flexibility:

- ✓ **Reduces the extent of leading edge separation**
- ✓ **Enhances lift at the cost of increased L/D**
- ✓ **Reduces nose down pitching moment**

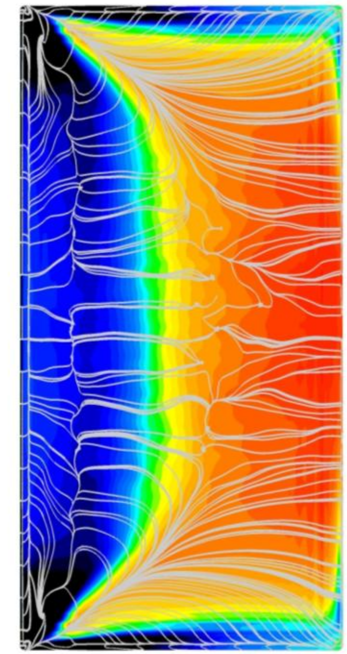
Rigid, Flat Wing



Rigid, Cambered Wing



Flexible Wing



	C_L	C_D	L/D	C_{my}
Rigid-Flat	0.965	0.235	4.112	-0.160
Rigid-Cambered	1.020	0.269	3.794	-0.140
Flexible Membrane	1.024	0.262	3.903	-0.122

Control of Low Reynolds Number Flows with Fluid-Structure Interactions

I Gursul, Bath

<u>Objectives:</u>

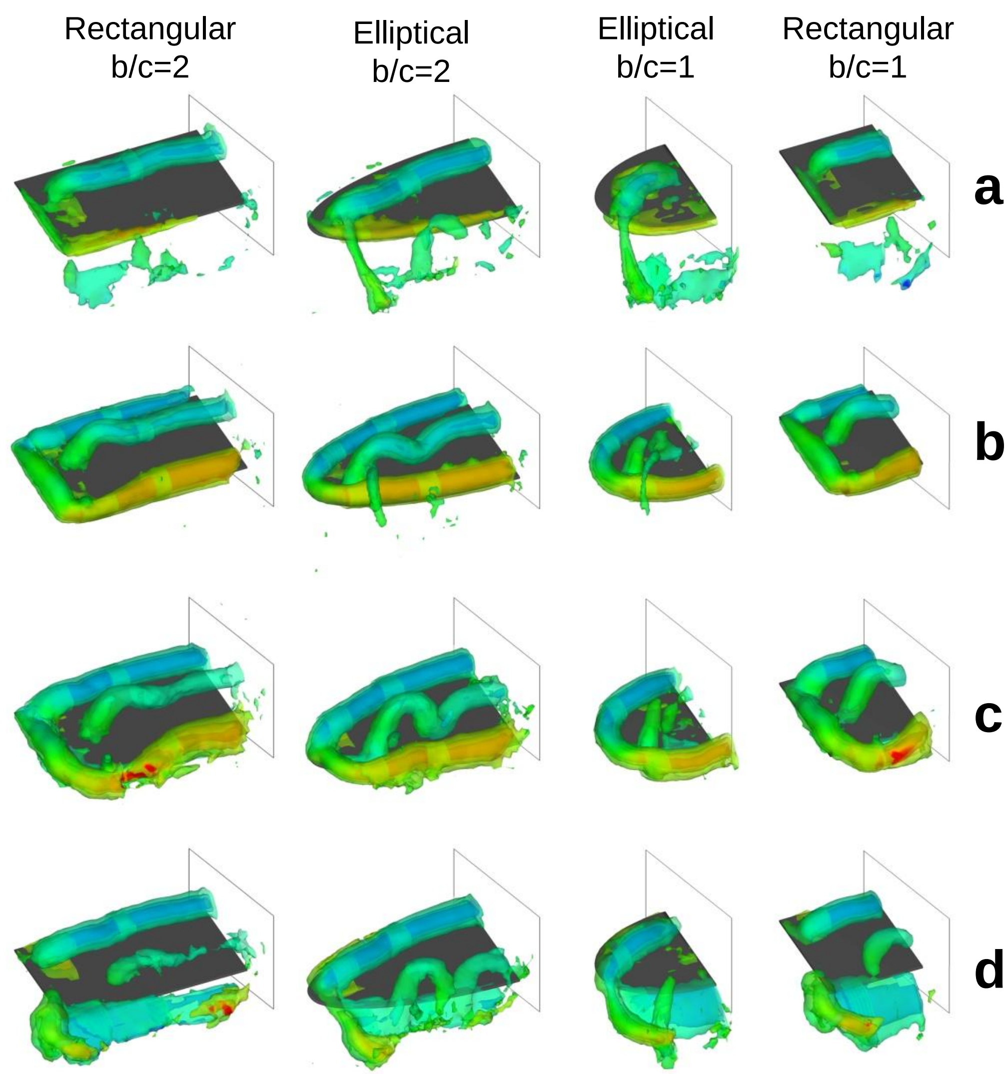
(i) exploit fluid-structure interactions to delay stall and increase lift of airfoils and wings at low Reynolds numbers

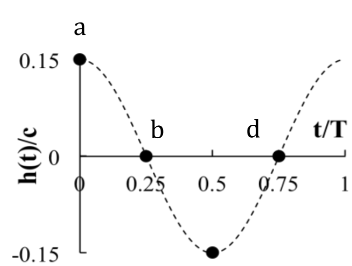
(ii) improve maneuverability and gust response of MAVs.

<u>Approach:</u>

(i) simulate aerolastic vibrations by means of ***small-amplitude plunging*** oscillations of airfoils and wings

(ii) develop flexible wings based on this knowledge.





Flapping-Wing Vortex Formation and Scaling

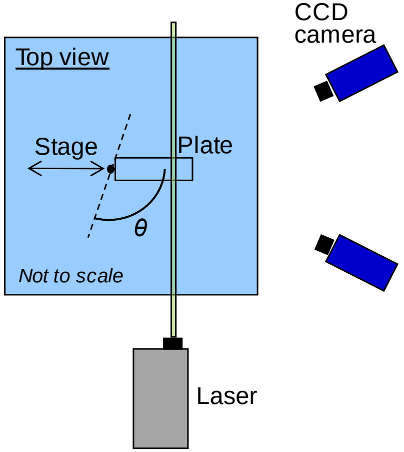
M. Ringuette (YIP 2010), Buffalo

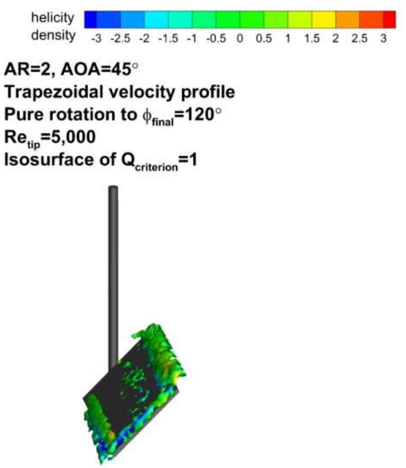
Objective …

- **find a scaling parameter connecting the vortex formation/strength to the kinematics, which should relate to important force features if a formation-parameter scaling holds**

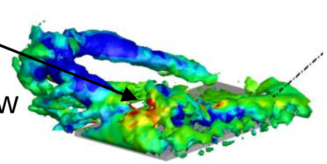
Approach …

- **characterize the general 3-D vortex topology**
- **track how the vortex loop evolves in space and time**
- **find the effects of non-dimensional parameters such as AR, Rossby no., on strength, vortex loop stability**

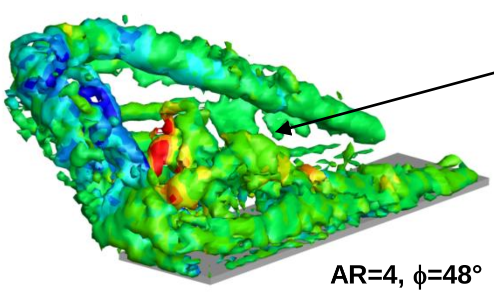




- TV flow anchors LEV to plate, prevents shedding
- Colors indicate flow along vortices



AR=2, ϕ=48°



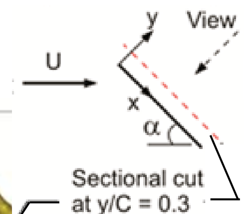
AR=4, ϕ=48°

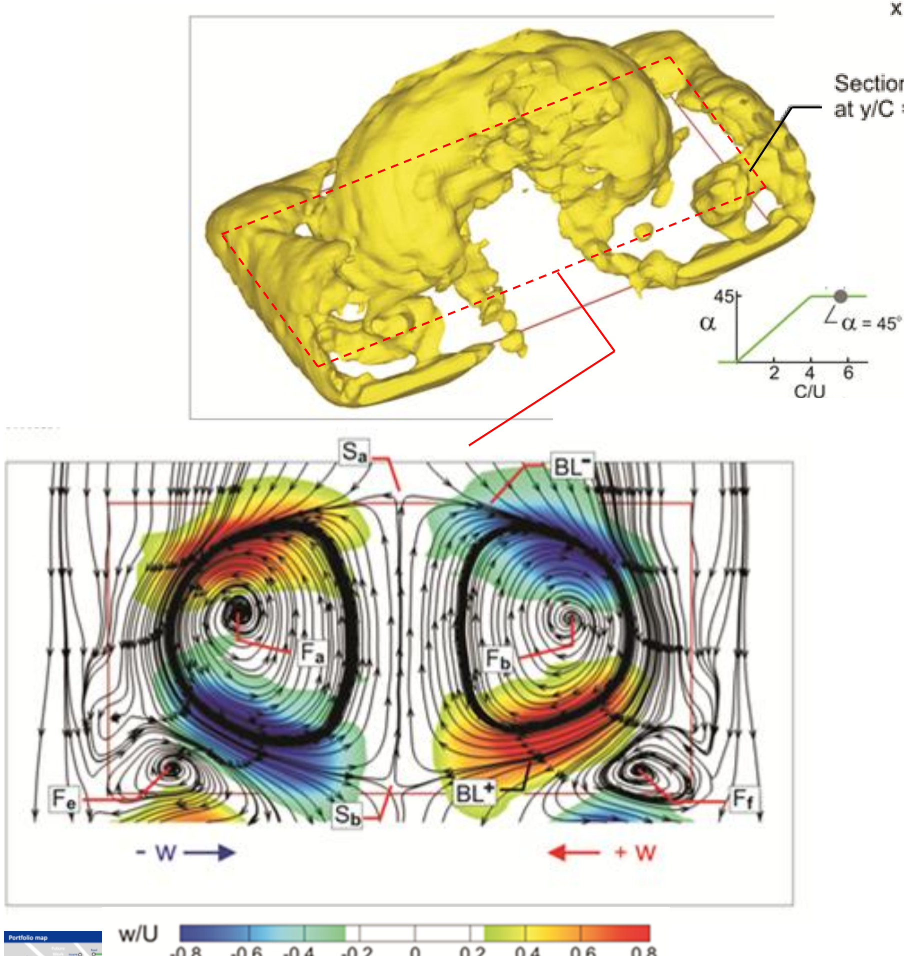
- Tip vortex effect insufficient to anchor LEV, observe shedding & eventual breakdown of vortex structure

Three-dimensional Vortex Formation On A Pitching Wing

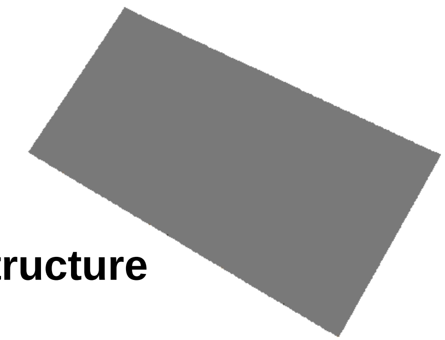
D. Rockwell (Lehigh) & M. Visbal (AFRL/RBAC)

Experiments

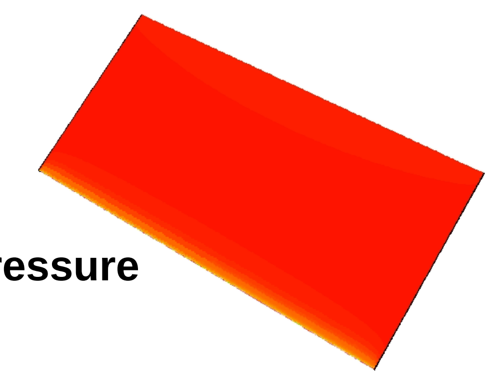




Simulations



Vortex structure



Surface pressure

High-Resolution Computational Studies and Low-Order Modeling of Agile Micro Air Vehicle Aerodynamics

J. Eldredge, UCLA

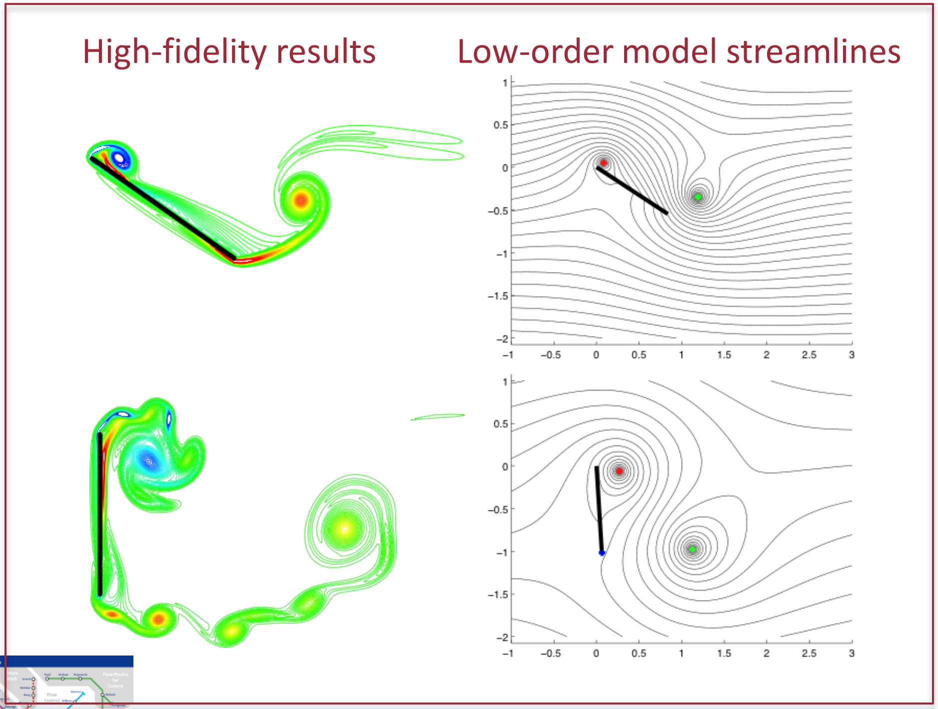
OBJECTIVES

- Develop **low-order phenomenological models** (< ~10 dof for flapping wing flight,
- Examining a progression of canonical wing motions, with both rigid and flexible wings.
- Simultaneously explore the physics of canonical wing motions using **high-fidelity numerical simulations**.

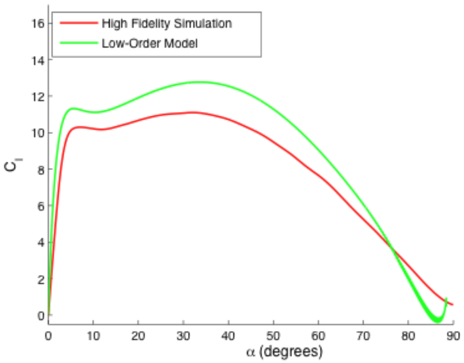
MAIN ACHIEVEMENTS

- Constructed a low-order model based on point vortex dynamics
- Successfully demonstrated that model captures force generated by a 2-d flat plate in pitch-up
- High-fidelity simulation requires ~1,000,000 degrees of freedom; low-order model requires only 6

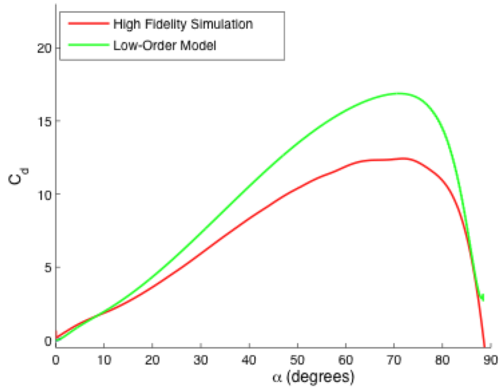
RAPID PITCH-UP



Lift vs Angle of Attack



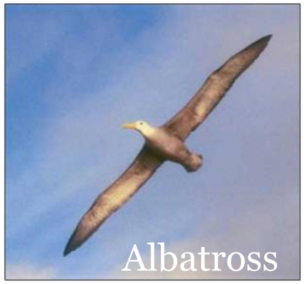
Drag vs Angle of Attack



Energy Extraction From Unsteady Winds

Williams (IIT)/ Colonius (Caltech)

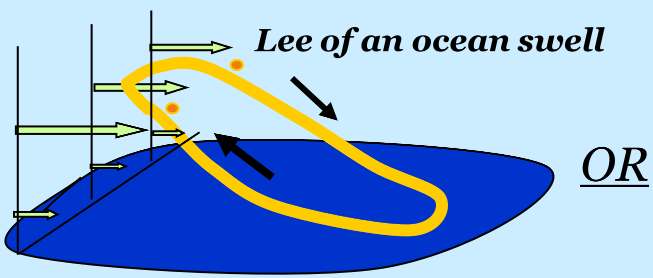
Albatross remains aloft indefinitely!



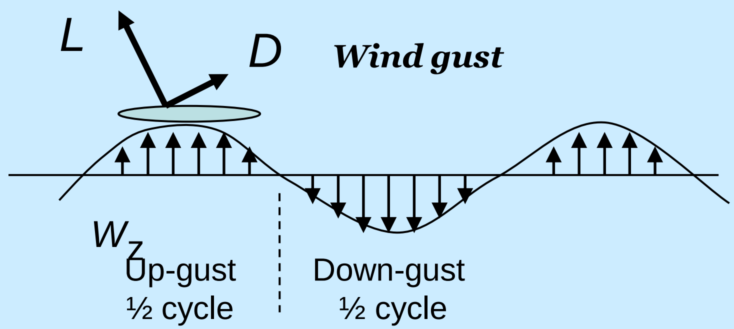
Model gliders flying at 400+ mph!!

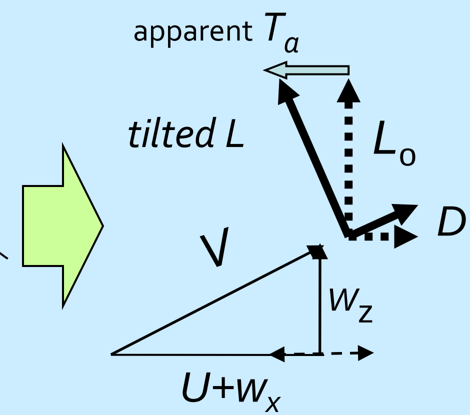
How? … DYNAMIC SOARING!!

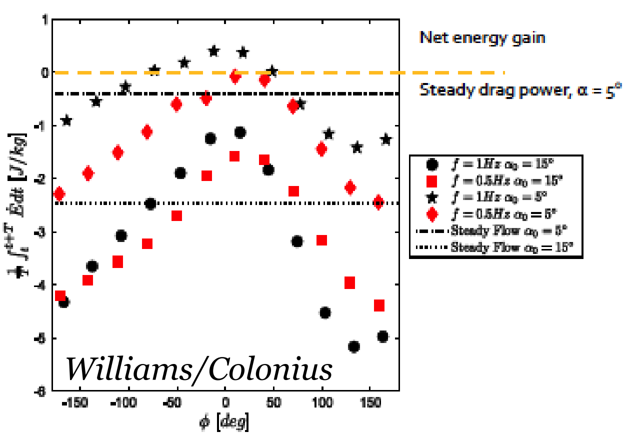
Extracting energy from _spatial velocity gradients_ in the wind.



OR







- Investigate unsteady and nonlinear phenomena relevant to gusts over wings
  - Without flow control can extract energy from flow
- Integrate active closed-loop flow with flight control
  - Demonstrate benefits of increased range and endurance by extracting energy from gusting flows

Transformational Computing in Aerospace Science & Engineering

To create transformational approaches in computing for aerospace science and engineering.

"How can we exploit <u>quantum computing</u> architectures specifically to advance aerospace computing?"

Applications of QC in Aerospace S&E

Meyer et al, UCSD

H sim | Fourier X-form | Phase est. | Ampl amplif

QA

$L\,y = x$

Investigate QC improvements in…

1. Solving systems of ODEs
2. Optimization of (non)smooth fcns
3. Evolving the gnd state of a molecule

Quantum Speedup for Turbulent Combustion Simulations

Givi et al, Pitt

LES of Turbulent Reacting Flows

Resolved large scales | SGS model

FDF SDE

- Develop quantum sim techniques for stochastic diff eqs (SDEs)

PMs: Drs. Douglas Smith & David Stargel, RSA
Partners: Drs. Curcic, Fahroo, Luginsland